The power-damping control law for a VSC is proposed as

$$\frac{d\Delta\omega}{dt} = -K_p K_f K_d(\omega - \omega_{set}) - K_p K_f \delta - K_p(P - P_{set}) \quad (10)$$

The relationship between the VSC frequency and the load angle is

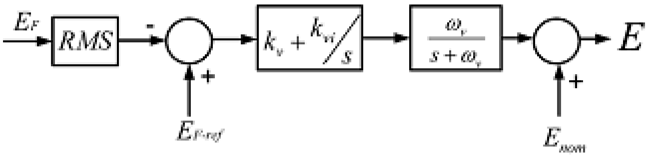
$$\frac{d\delta}{dt} = \Delta\omega \quad \text{........\dots\dots\dots\dots\dots\dots\dots\dots} \quad (11)$$

To eliminate the switching effect superimposed on the real power, a low-pass filter can be adopted and the filtered power (average power) is fed to the controller. This low-pass filter also gives more degrees of freedom in the control design and may introduce more damping for angle and frequency oscillations.

B. Voltage Controller

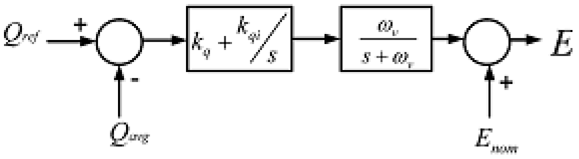
The reactive power of a DG unit can be controlled to 1) regulate the terminal voltage (PV bus) or 2) achieve a specific output reactive power (PQ bus). The Fig. 3(a) & (b) shows these two different variants. In the first, the voltage reference is compared to the actual output voltage. In order to track the reference voltage, a proportional-integral (PI) controller is employed aiming at compensating the input error by proper adjustment of VSC's output voltage.

The output of the PI controller is processed by a low-pass filter and finally the VSC's voltage amplitude reference is obtained. The low-pass filter plays two different roles. First, it offers more degrees of freedom to tune the low-pass filter cut-off frequency and PI controller parameters such that satisfactory transient and steady-state performances are achieved. In weak grids, usually it is essential to regulate the grid-voltage at the point of common coupling, thus PV bus is the common approach in weak grids.



(a)

Figure 3(a): P-V Bus Control



(b)

Figure 3(b): P-Q Bus Control

An alternative to the voltage control is reactive power regulation as shown in Figure 3. (a). However, this is not the common case in weak grids. This is due to the fact that the P-Q control strategy significantly degrades DG stability in weak grids as compared to the P-V control. Similar to Figure 3. (b), a low-pass filter exists after the PI controller to mimic the flux decay behavior of an SG. This low-pass filter allows the suppression of voltage oscillations while voltage tracking time-response and steady-state error are still kept within acceptable limits. With the help of MATLAB SIMULINK the PWM signal is generated.

A closed loop is made for continuous measure of voltage and current in grid. If any change occurs the controller will make necessary modifications and give a PWM signal to VSC. The VSC will supply real or reactive power to weak grid according to its need.

3. Enhance Performance Under Different Power Levels

The simulation is carried out using the test system (Fig.4) and the parameter of controllers inputs are referred from standard IEEE papers. The simulation study is conducted in MATLAB/SIMULINK model.

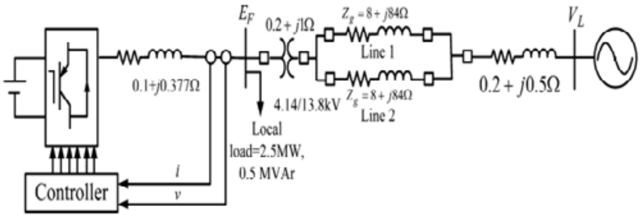


Figure 4: Simulated Test System

The system is composed of a 7.0 MW VSC, filter, local load, transformer and an interface line connecting the VSC to a grid. The impedance 0.2+ j0.5Ω is the equivalent impedance of the stiff source referred to the distribution level. The simulation study was conducted The DG unit supplies the local load at its output terminal and is connected to a stiff grid through a very weak interface with total impedance of 43.7Ω . Since the connecting line is almost inductive, the power capacity of the interface line is approximated by

$$P \cong \frac{E_F V_L}{X} Sin\delta_F \quad \text{\dots\dots\dots\dots\dots\dots....} \quad (11)$$

Where the notations are defined in Fig. 1and X is the total reactance of the transformer, line and stiff grid(X=42+1+0.5=43.5Ω). Therefore, the maximum real power transfer capacity of the connecting line is equal

$$P_{max} = 13880^2/43.5$$
$$\approx 4.44\text{MW}.$$

Since the local load power at the rated voltage is 2.5 MW, thus the VSC's maximum power capacity is about 7 MW. The DG works as a PV bus aiming at keeping the filter output voltage (E_F) constant during grid connection. System performance at low- and high-power references, transition to islanding, self -synchronization is studied.

Table 1: Controller Parameters

Parameter	*Value (SI units)*
VSC maximum power capacity	7MW
VSC voltage (L-L $_{rms}$)	4160V
$E_{f\text{-}ref}$(Phase maximum voltage)	3400V
K_f	5
K_d	$1*e^5$
K_p	0.1
K_v	200
K_{vi}	100

4. Simulation Scenario

A. Power Injection and Grid Restoration

The simulation response of real power, voltage and current are shown in Fig.5 and the frequency response is shown in Fig.6.

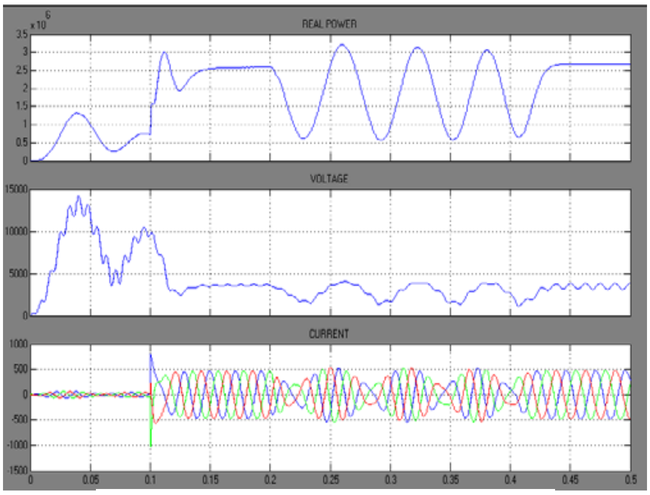


Figure 5: Output waveform of Real Power

Low Power Injection

To study the behavior of the controller in a wide range of operating points, it is assumed that we are having only single load till 0.1s.the power reference is increased from 0.5MW to 1.5MW it has a slight oscillation and remain stable in 0.8MW.Here the current is less with severe oscillations and voltage magnitude is increased with high oscillations.

High Power Injection

At t=0.1s, the load circuit breaker is closed and one more load is added .the reference power is varied between1.5MW to 3.0MW.The response is smooth but with larger rise time; however, it is still stable with damped response and the output power reaches 2.5MW. The current is also increased and the voltage oscillations are reduced.

Transition to Islanded Mode

Islanded operation is another scenario that may occur in DG applications to supply local critical loads. At, t=0.2s the VSC is switched to the islanded mode due to a fault in the grid. No controller-mode switching action or reconfiguration is required. While referring the waveforms there are oscillations in the power, voltage and current.

Grid Restoration

It is common that a recloser automatically reconnects a DG unit to the main grid after a special time period (usually 1 s). This is due to the fact that most of faults are cleared after few cycles. In this case, connection occurs without synchronization which may lead to severe transients as a result of frequency and angle mismatch of both sides of the recloser at the moment of connection. Weak grids suffer more from the resynchronization transients. The real power response is 2.5MW.The response is smooth and well damped. Even the current oscillation is also damped.

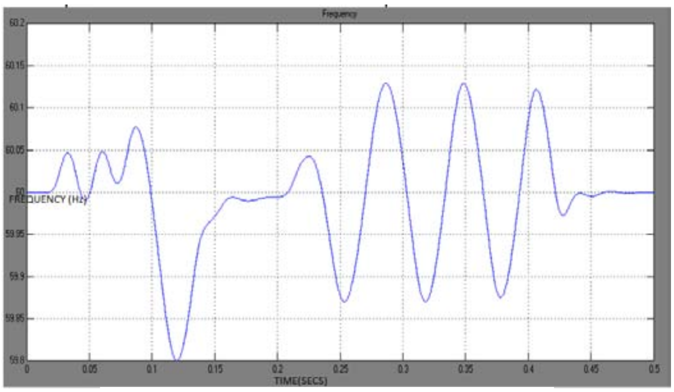


Figure 6: Output Waveform of Frequency

Case 1: The frequency is having a higher value till 0.1s and also oscillations for low power injection.
Case 2: In this case 0.1s to 0.2s it shows a lesser value almost close to zero for high power injection.
Case 3: While noticing the frequency wave in the islanding mode it got lot of disturbances from 0.2s to 0.4s.
Case 4: But after grid restoration there is a stable frequency of 60 Hz from 0.45s.

5. Conclusion

This paper gives a new control method to improve the performance of the weak grids. The linear power damping controller mimics SGs with extra power damping-synchronization capability providing self-synchronization with the grid which eliminates the need for a PLL. A wide variety of scenarios have been applied to verify the effectiveness of the proposed linear controller. System performance at low and high-power references, transition to islanding, self-synchronization is studied.

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Author Profile

Mrs. R. Kavitha has received her B.E degree in Electrical and Electronics Engineering from Vellore Institute of Technology, Madras University, Chennai, Tamilnadu, India in 2000. She is currently pursuing her M.E degree in Power System Engineering from the Department of Electrical Electronics and Engineering, Valliammai Engineering College, Anna University, Chennai, Tamilnadu, India. Her research interests cover many aspects of power system engineering including smartgrids and micrograds, power electronics and renewable energy resources.

Mrs. N. Priya has received her B.E. degree in Electrical and Electronics Engineering from Adhi Parashakthi Engineering College, Madras University, Melmaruvathur, Tamilnadu, India in 2002. She received her M.E degree in Power Electronics and Drives from College of Engineering Guindy, Anna University, Chennai, Tamilnadu, India in 2011. Her current research interests includes renewable energy resources and power optimization. She is a member of ISTE.